RESULTS OF THE 2015 HELIUM PROCESSING OF CEBAF CRYOMODULES*

M. Drury†, F. Humphry Jr., L. King, M. McCaughan, A. Solopova
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

Abstract

Many conference series have adopted the same The CEBAF accelerator at Jefferson Lab consists of an injector and two linacs connected by arcs. Each linac contains 25 cryomodules that are designed to deliver an integrated energy of 2.2 GeV per pass to an electron beam in order to meet 12 GeV energy requirements. Helium processing is a processing technique that is used to reduce field emission (FE) in SRF cavities. Helium processing of the 50 installed linac cryomodules was seen as necessary to support 12 GeV energy requirements. This paper will describe the processing procedure and summarize the results of this effort.

BACKGROUND

In the summer of 2015, Jefferson Lab undertook a program to helium process all of the cavities in cryomodules that were installed in the CEBAF linacs. This work was deemed necessary to establish a robust SRF energy gain in support of high availability 12 GeV operations [1].

Reducing field emission from the SRF cavities would have several benefits. First, in the case of the original CEBAF cryomodules (denoted as C20's), a reduction in field emission would lead to a reduction in the rate of periodic window arcing. This is a phenomenon associated with the fundamental power coupler design used in these cryomodules. Field emission in the cavity causes electrostatic charging of the cold RF window which, in turn, causes periodic arcing. The rate of arcing is directly related to the magnitude of field emission [2]. Thus, reducing fields emission levels and increasing the field emission onset gradient would allow higher operating gradients in these older cryomodules. In 2015, there were 30 of the original C20 cryomodules installed in the lin-acs and injector. In addition, there were 11 refurbished C20 cryomodules (C50's) and 11 new high gradient cryomodules (C100's) installed during the 12 GeV upgrade.

Second, a reduction in field emission would, in many cases, result in a reduction in the dynamic heat load for a given cavity. This could, in some cases, lead to higher operating gradients for the C50 and C100 cavities. Finally, the radiation levels around the C100 cryomodules are high enough to cause damage to materials such as cable insulation and to electronics that are located near the C100 cryomodules. High radiation levels also appear to be responsible for deteriorating beamline vacuums in the C100 zones. Reducing field emission would help to mitigate these problems and allow the C100 cryomodules to operate at higher gradients.

* Work supported by US DOE Contract No. DE-AC05-06OR23177
† drury@jlab.org

SET UP AND EQUIPMENT

The program was allotted a 4-month time span during the summer maintenance shutdown in 2015. Based on the amount of time available, it was decided to set up four processing stations; two in each of the linacs that comprise the CEBAF accelerator. Each processing station consists of a pumping cart located in the tunnel adjacent to the cryomodule and a control and data acquisition station upstairs in the service building.

Pumping Carts

The pumping carts contain all of the hardware necessary to safely introduce and monitor gaseous helium into the beamline of cold cryomodule (See Figure 1). Using these carts, 99.9999% pure helium is introduced into the cryomodule beamline vacuum through a 0.003 µm filter and a variable leak metering valve. A residual gas analyser (RGA) is used to measure the partial pressure of helium in the beamline. The RGA is backed up by two full range vacuum gauges. A turbo pump is included for pumping out helium at the end of the processing phase.

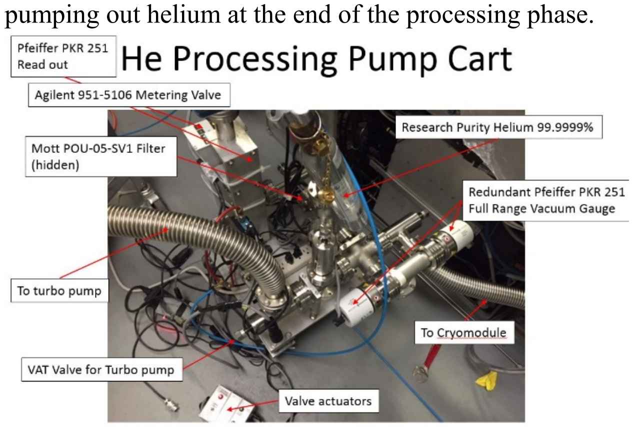

Figure 1: Pump Cart.

Control Stations

Each control station upstairs includes a PC running Windows and Labview. Each PC is able to communicate with a Field Control Chassis (FCC), power meters, a frequency counter, and the accelerator control system (EPICS). Radiation monitoring is accomplished using the DecaRad system. The DecaRad is a ten channel data acquisition system that connects to ten channels of Geiger-Mueller (GM) tubes and monitored via EPICS. The set of ten GM tubes are positioned around a cryomodule according to the diagram in Figure 2.

The top layout is used for the C100 cryomodule design. The bottom layout is for original design C20 and C50 cryomodules.

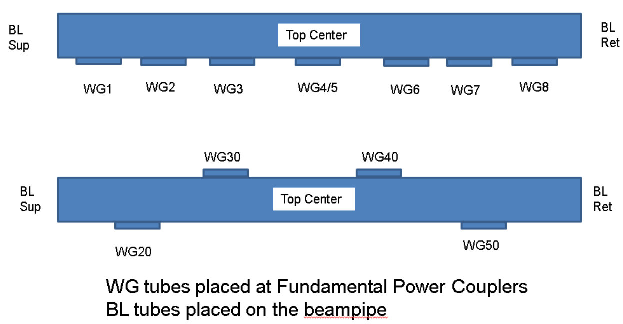

Figure 2: GM Tube Layouts.

PROCEDURE

The processing procedure consisted of four major steps. First, the field emission characteristics of the cavities in a cryomodule were measured to create a baseline. Data from the DecaRad was collected while ramping up the cavity gradient until a fault condition, such as a quench, was reached. This data was used, in part, to determine whether to process the cavity. If the radiation was very low or non-existent, then the cavity was not processed. Figure 3 shows a typical plot of field emission data from a DecaRad for a single cavity.

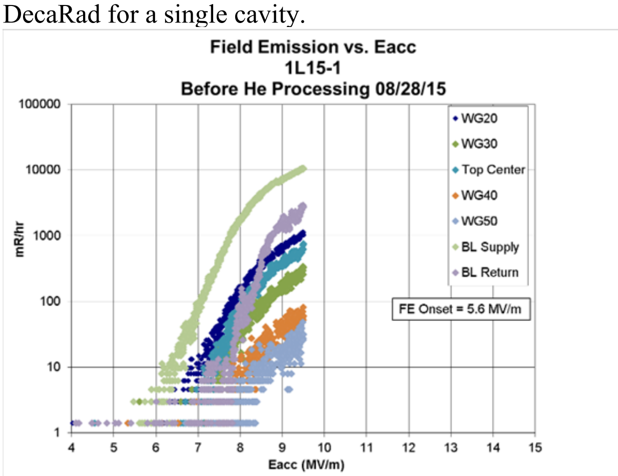

Figure 3: Field Emission Graph.

Once the baseline measurements were completed, helium was introduced into the beamline vacuum. The target partial pressure is in the mid 1×10^{-5} torr range. The process of reaching a stable target pressure can take as long as eight hours.

After a stable pressure is reached, processing can begin. Gradient is established in the cavity to be processed. The cavity was then ramped up to a target gradient for processing. The cavity would then be operated at that gradient until there were no further improvements in radiation production. Since time allotted for helium processing was fixed, it was necessary to place some limits on the amount of time that available for processing.

Once processing for a given cryomodule had been completed, a partial warm up of the cryomodule was performed with the beamline vacuum open to the turbo pump on the pumping cart. This was done to remove the helium. Typically, the warm up proceeds until cavity temperatures reach 30 K – 40 K. The temperature cycle takes approximately 24 hours to complete.

The last step is acquiring a new set of radiation measurements in order to document any improvements.

OBSTACLES TO PROCESSING

The suitability of a particular cryomodule or cavity for processing could, in some cases, be compromised by vacuum problems. Some of the older cryomodules have cold RF window leaks that allow the injected helium to leak through into the waveguide vacuum. If the leak is large enough, an increase in arcing events between the RF windows makes it difficult or impossible to establish gradient in the cavity. Pumping helium out of the waveguide vacuum space reduces the partial pressure of helium in the cavity to the point that processing becomes unfeasible. In other cases, the beamline vacuum valves at either end of the cryomodule can have leaks due to the degradation of the viton seals. In some case, these leaks are large enough to prevent the establishment of a stable pressure regime and requiring frequent recharging of the beamline vacuum with helium. In this situation, attempts to process can proceed but the success of the attempt is somewhat dependent on the size of the leak.

Ten cavities were not processed due to cold window leaks.

C100 Cavities

While attempting to process the C100 cryomodules in the South Linac, several events occurred that led to a cessation of processing of these cryomodules. In each case, while processing a C100 cavity, a cavity quench event was followed by a dramatic increase in field emission and a new, much lower, maximum gradient. These were most likely the result of the creation of a new field emission site in the cavity.

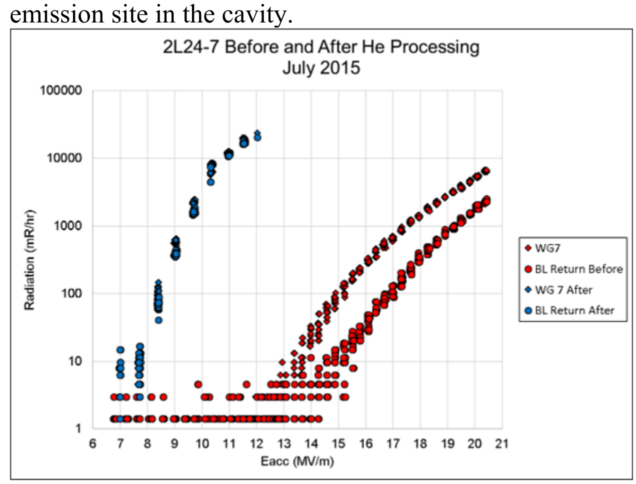

Figure 4: Cavity Performance Loss.

Figure 4 shows the results of one such event. The figure shows both the drastic change in field emission and in maximum gradient.

Although there were only a few of these events, they had a drastic enough effect on cavity performance that processing of the C100 cryomodules was stopped until further study could be undertaken. As a result, four of the C100 cryomodules were not processed.

In the end, 45 cryomodules (360 cavities) were processed with 46 of those cavities left unprocessed for various reasons.

RESULTS

In order to gauge the effectiveness of the processing effort, we looked for changes in the field emission onset gradient, changes in the magnitude of field emission and, most importantly, resulting changes in the energy reach of the accelerator.

Figure 5 shows the distribution of changes in the gradient at which radiation becomes detectable by the DecaRad system.

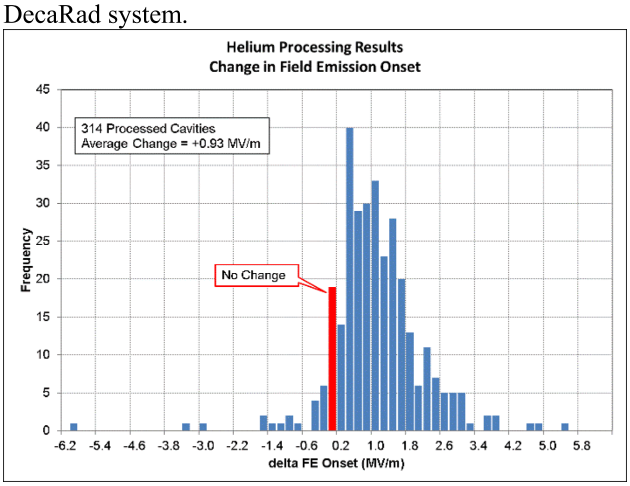

Figure 5: Changes in FE Onset.

The average increase in FE free gradient was 0.93 MV/m. Roughly 12% of the cavities saw no change or a decrease in onset gradient.

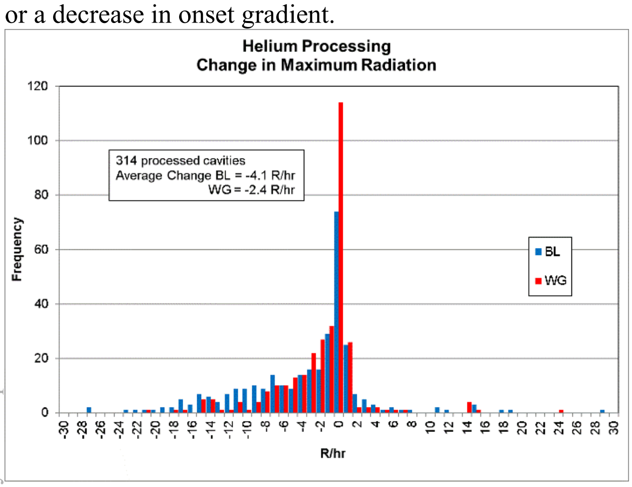

Figure 6: Changes in Maximum Radiation.

Figure 6 shows the distribution of changes in maximum radiation as measured at the beamline and at the waveguides. The radiation data has been grouped by GM tube locations into beamline (BL) and waveguide (WG) components (See Figure 2). The average reduction in maximum radiation per cavity was 4.1 R/hr as measured at the beamline and 2.4 R/hr at the waveguides.

Finally, Figure 7 shows the effect that the processing effort had on the energy reach of the CEBAF accelerator [3].

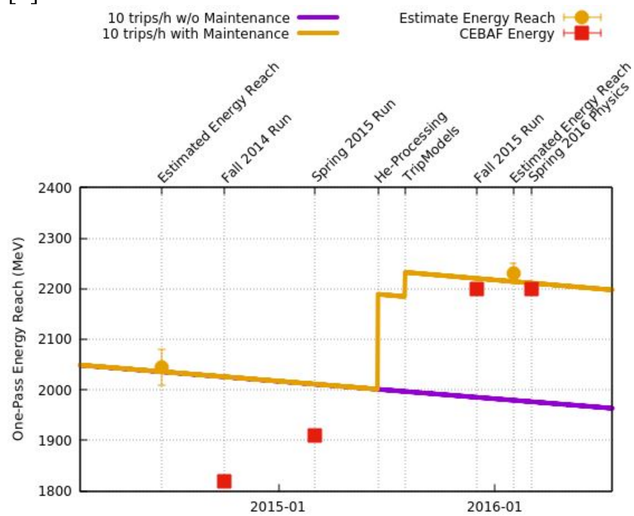

Figure 7: CEBAF Energy Reach.

The gold line is an estimate of the changes in the energy available per single pass with a ten per hour trip rate. The gold dots are actual measurements of the energy reach. The large step on that line at the midpoint of the graph is due to the helium processing effort. This was a gain of 201 MeV per pass and raised the available energy to 2.2 GeV per pass. This energy gain is roughly equivalent to what would be obtained by upgrading eight of the original C20 cryomodules to the C50 design.

SUMMARY

In the summer of 2015, an effort was undertaken to improve SRF cavity performance through field emission reduction using the helium processing technique. This effort was undertaken to address the energy needs of the upcoming 12 GeV program which required 2.2 GeV per pass from the linac cryomodules. Over a four-month period, 314 cavities in 45 cryomodules were processed. As a result of this effort, the energy reach of the CEBAF accelerator was raised by 201 MeV per pass making it possible to reach 2.2 GeV per pass. References to supplementary material on helium processing are included at the end of this paper.

ACKNOWLEDGMENTS

This work would not have been possible or successful without the hard work and dedication of my co-authors who worked extremely long hours throughout the summer of 2015.

REFERENCES

[1] A. Freyberger, Commissioning and Operation of 12 GeV CEBAF, in *Proc. Int. Part. Accel.* Conf. 2015, Richmond, Virginia (2015), pp. 1-5.

[2] P. Kneisel, *et al*., Response of CEBAF's cold RFWindow to Operation in FE-Regime of a Cavity, CEBAF Tech-note TN94-029.

[3] A. Freyberger, private communication, Oct 2016.

SUPPLEMENTAL MATERIAL

H. A. Schwettman, J. P. Turneaure, and R. F. Waites, Journal of Applied Physics 45, 914, 1974, "Evidence for surface-state-enhanced field emission in rf superconducting cavities".

C. Reece, M. Drury, M. G. Rao, and V. Nguyen-Tuong, Improvement of the Operational Performance of SRF Cavities via In Situ Helium Processing and Waveguide Vacuum Processing, in *Proc. 1997 Part. Accel. Conf*., 1997.

J. Knobloch and H. Padamsee, Microscopic Investigation of Field Emitters Located by Thermometry in 1.5 GHz Superconducting Niobium Cavities, Proc. 7th Int. Workshop on RF Superconductivity, Gif-sur-Yvette, France, 1995, pp. 95-103.

C. E. Reece, Achieving 800 kW CW Beam Power and Continuing Energy Improvements in CEBAF, Chicago, USA, 1998, pp. 448-450.

C. Reece, J. Benesch, and J. Preble, Refining and maintaining the optimal performance of the CEBAF SRF systems, 2001, pp. 1186-1188 vol.2.